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(56) Documents Cited
Electronics Letters,Vol.30,No.11,26 May 1994,pages 860-862 Optics Letters,Vol.19,No.6,15 March 1994 pages 387-389 Appl.Phys.lett.,62,(10),8 March 1993 pages 1035-1037

(58) Field of Search
UK CL (Edition M) G2J JGF
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(54) Incubated Bragg gratings in photosensitive waveguides

(57) A Bragg reflection grating is written in photosensitive optical fibre 11 using ultra-violet light from an ArF excimer laser 12 with the aid of a phase grating 10 to create a fringe pattern. The writing is effected by a type II damage process performed in two stages, the first of which involves the creation of a low reflectivity grating, which is incubated to greater reflectivity in the second stage. Incubation may be performed without the use of any fringe pattern.

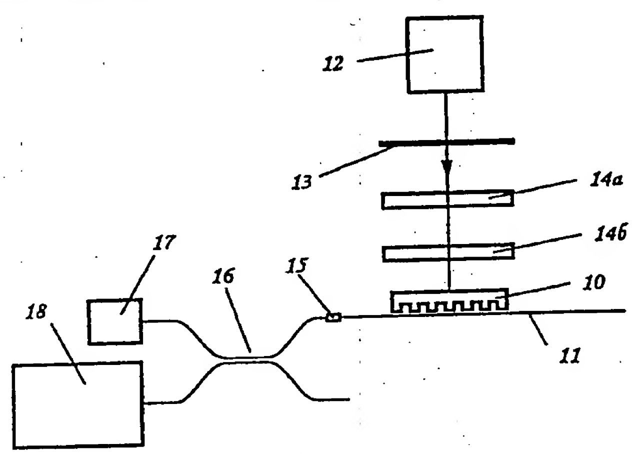

Fig 1.

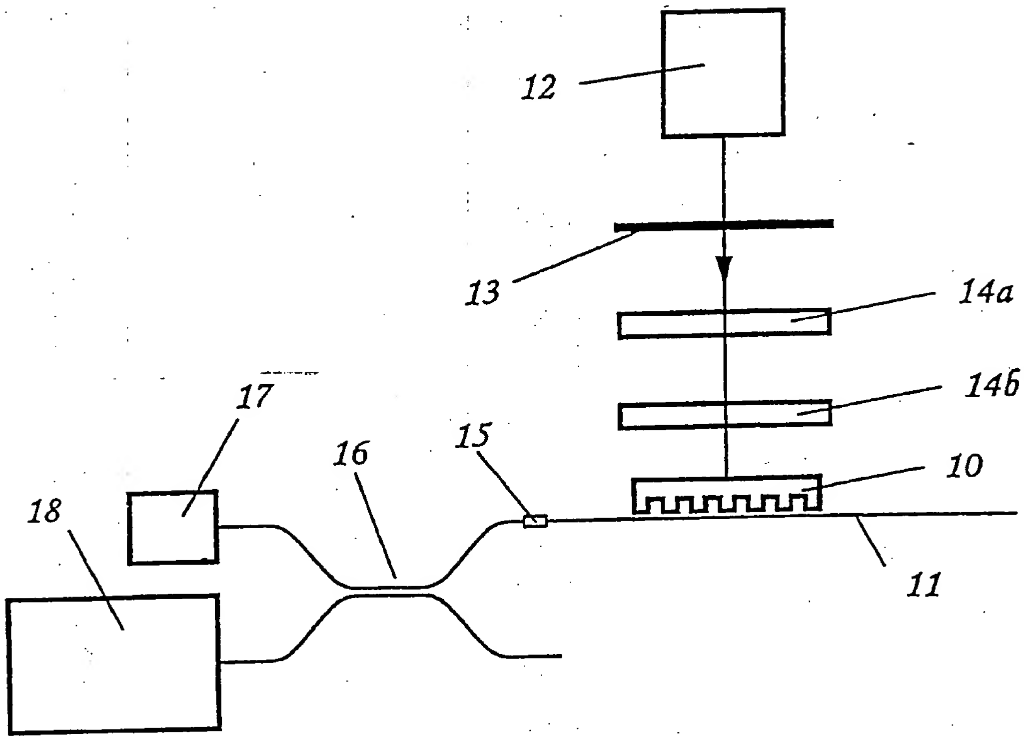

Fig 1.

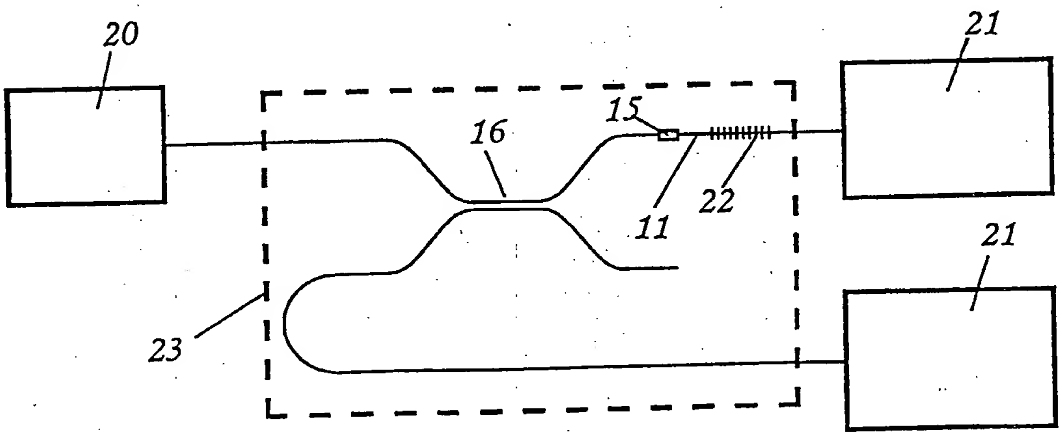

Fig. 2.

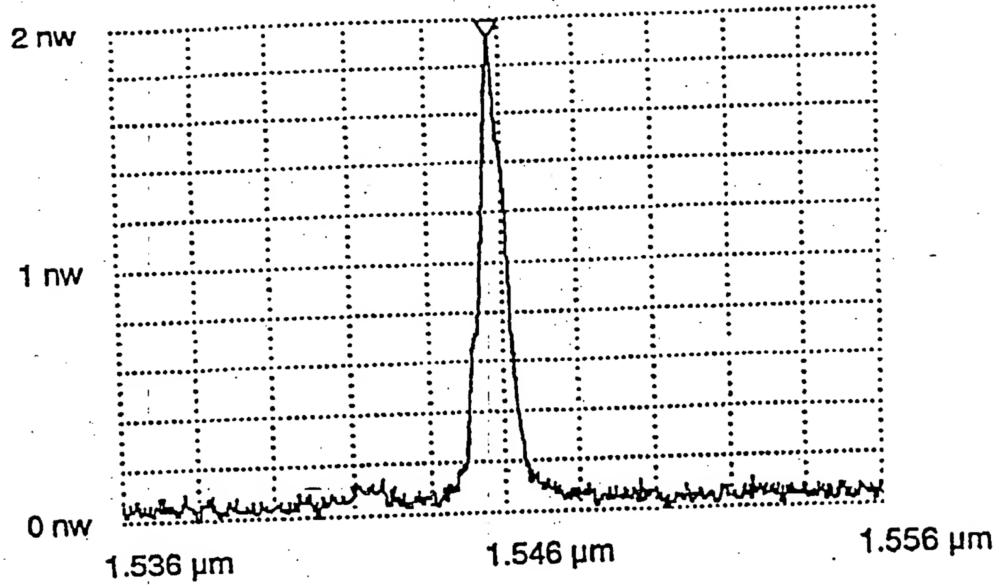
2 nw
1 nw
0 nw
1.536 µm
1.546 µm
1.556 µm

Fig. 3.

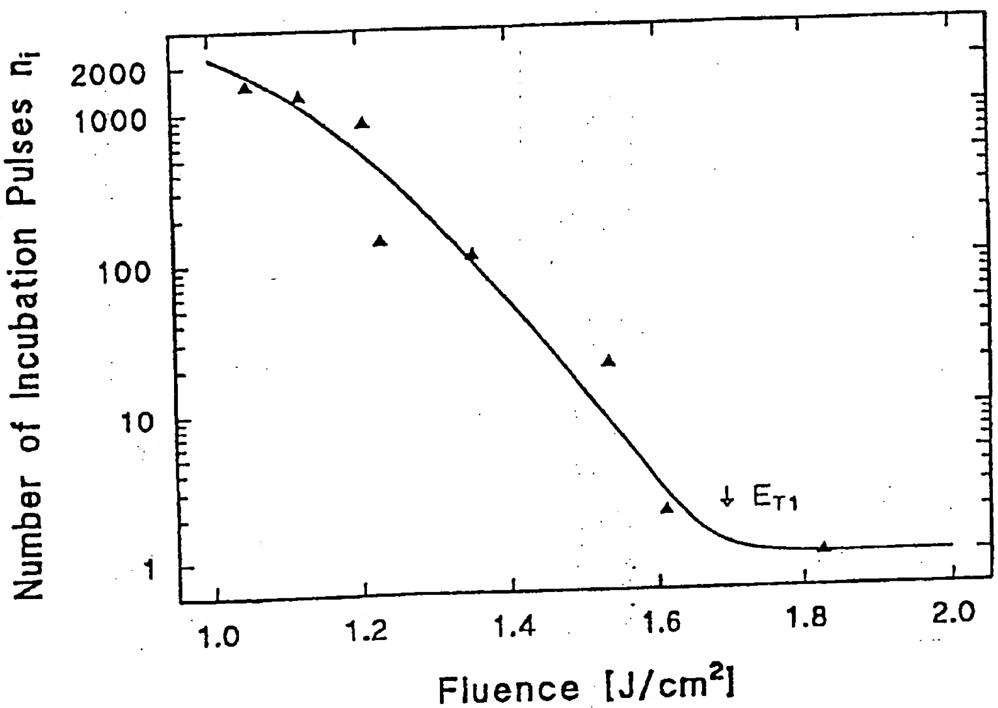
Number of Incubation Pulses n_i
2000
1000
100
10
1
E_{T1}
1.0
1.2
1.4
1.6
1.8
2.0
Fluence [J/cm²]

Fig. 4.

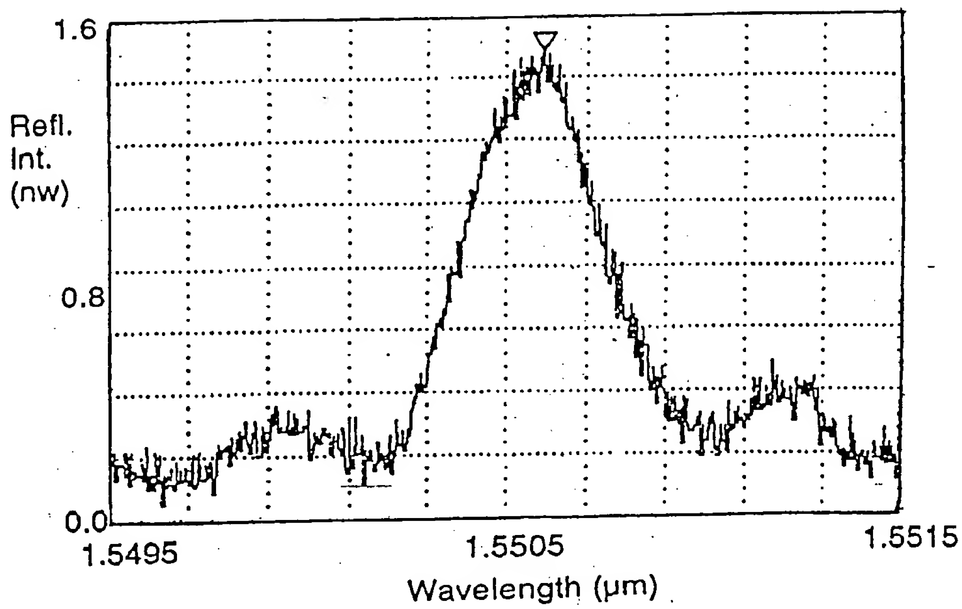
1.6
Refl.
Int.
(nw)
0.8
0.0
1.5495
1.5505
1.5515
Wavelength (μm)

Fig. 5.

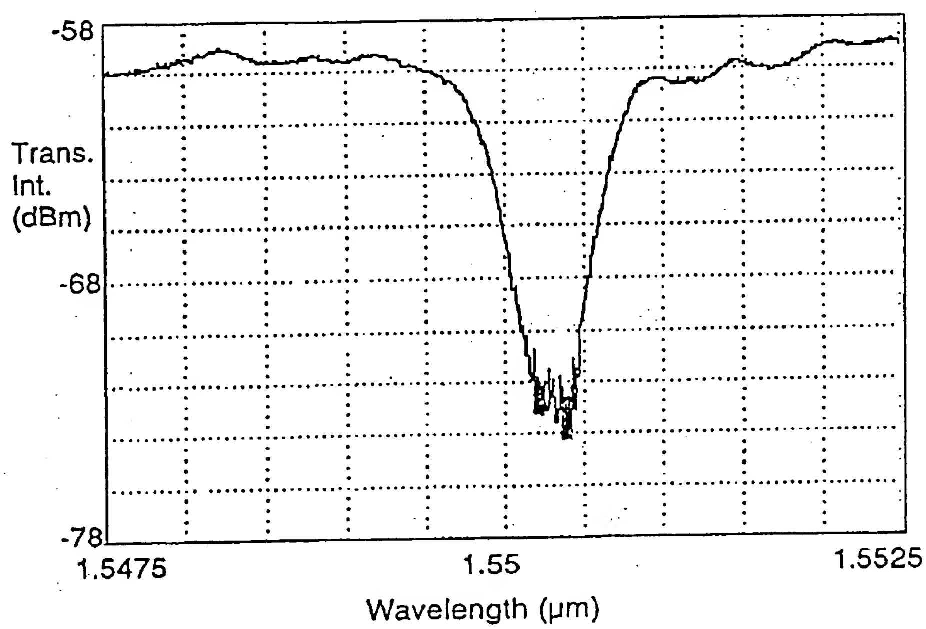
-58
Trans.
Int.
(dBm)
-68
-78
1.5475
1.55
1.5525
Wavelength (μm)

Fig. 6.

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INCUBATED BRAGG GRATINGS IN WAVEGUIDES

This invention relates to the creation of Bragg gratings in photosensitive optical waveguides. It is known that such a grating can be created by illuminating the photosensitive waveguide from the side, writing the lines simultaneously with an interferometrically generated grating fringe pattern of light. Such a fringe pattern can be created using two-beam interferometry, or as a fringe pattern generated in the vicinity of a diffraction grating, typically a phase grating, through which light is caused to pass.

Two broad regimes for producing gratings in photosensitive optical waveguides are known, respectively characterised as type I and type II. A type I grating is created by relatively low fluence exposure to a fringe pattern, and the refractive index change that is produced grows towards a saturation level with increasing fluence, which is normally, but not necessarily, provided on a cw basis. The manufacture of such type I gratings is for instance described in US Patent 4 474 427 (K O Hill et al) and US Patent 4 725 110 (W H Glenn et al). A type II grating is created by significantly higher fluence exposure to a fringe pattern, and the effect has been attributed to some 'damage' effect upon the core of the fibre. The manufacture of such a type II grating is for instance described by J L Archambault in a paper entitled 'High Reflectivity and Narrow Bandwidth Fibre Gratings Written by Single Excimer Laser Pulse', Electronics Letters (7 Jan 1993), Vol. 29 No. 1, pp 28-29. Published papers on type II grating creation have recited the use of ultra-violet radiation at 248 nm from a KrF excimer laser, the fluence being confined to a single pulse typically of about 20 ns duration. The

suggestion that the observed effect is a 'damage' effect is based upon observation of the effects of such fluences incident upon fibre preforms similar to those from which the optical fibres themselves were drawn. Damage is inferred when ablation from the surface of preforms is detected using a sensor that directs an interrogation beam of laser light laterally through a zone just above the point where the 248 nm ultra-violet light is incident upon the preform surface. When using a KrF excimer laser in this way, it is found that there is a relatively narrow safety margin between the fluence necessary to reach the lower threshold of the onset of refractive index modifying 'damage', and the fluence necessary to reach the upper threshold at which catastrophic disruption of the fibre is liable to occur.

For the purpose of this invention the term 'damage', as used in the context of Bragg grating creation, is defined to cover a process of creating a Bragg grating in a photosensitive waveguide using a fluence sufficient to produce ablation effects when applied to an optical fibre preform having the same optical core composition as that of the waveguide.

The present invention is directed to the avoidance of these problems associated with the creation of 'damage' type Bragg gratings using single pulse 248 nm radiation.

According to the present invention there is provided a method of creating a Bragg grating in a photosensitive optical waveguide wherein a seed Bragg grating of relatively lower refractive index difference modulation depth is created by exposure of the waveguide to a fringe pattern of illumination using one or more pulses of electromagnetic radiation of sufficient fluence to induce 'damage', as hereinbefore defined, and wherein said modulation depth is enhanced to a relatively higher refractive index difference modulation depth value by exposure of said seed Bragg grating to one or more further pulses of electromagnetic radiation of sufficient

fluence to induce further 'damage' in the previously 'damaged' regions of the seed grating.

The exposure of the seed grating to further fluence in order to enhance its modulation depth, which procedure may be termed 'incubation' of the grating, does not require the use of a fringe pattern, and so incubation can readily be performed at a different location from that at which the initial creation of the seed grating takes place. This facilitates the creating of such Bragg gratings in optical fibre as that fibre is being drawn from preform.

There follows a description of the creation of Bragg reflector gratings in optical fibres by methods embodying the invention in preferred forms. The description refers to the accompanying drawings in which:-

Figure 1 is a schematic diagram of apparatus employed to create a seed Bragg grating,

Figure 2 is a schematic diagram of apparatus employed to analyse the spectral properties of seed or incubated Bragg grating,

Figure 3 is a plot of the spectral reflectivity of a first example of Bragg reflector,

Figure 4 is a plot of the number of incubation pulses required to initiate damage, measured as a function of pulse fluence, and

Figures 5 and 6 are plots respectively of spectral reflectivity and transmission of a second example of Bragg reflector.

A seed Bragg grating is created in a waveguide by laterally illuminating it with an interference fringe pattern of high intensity ultra-violet light. In the case of the apparatus of Figure 1 this fringe pattern is generated with the aid of a diffraction grating, in particular a phase grating 10, upon which the ultra-violet light is normally incident. The depth of the grating elements of this phase grating is designed to suppress the zero order diffraction pattern. The waveguide in which the Bragg grating is to be created is a length 11

of single mode optical fibre which is located almost in contact with the grating 10 which is oriented so that its grating lines extend transversely of the fibre axis, preferably at right angles to that axis. Light from an ultra-violet emitting laser 12 is directed via a rectangular aperture 13 (to select the central substantially uniform fluence region of the laser's emission) and via two cylindrical lenses 14a and 14b on to the grating 10 so as to form a generally rectangularly shaped spot whose length is substantially matched to the length of the grating 10 and whose width may similarly be substantially matched to, or somewhat greater than, the width of the fibre 11. For monitoring purposes, the fibre 11 may be spliced at 15 to a 3dB single mode 3dB fibre coupler 16 so that the reflection of light launched into the fibre 11 from and ELED 17 can be monitored on some form of spectrum analyser 18. This monitoring arrangement is suitable for monitoring the creation of the Bragg reflector, but does not have the spectral resolution to measure the bandwidth of that reflector. This can be measured, as depicted in Figure 2, by replacing the ELED 18 with a tuneable diode laser source 20 which is scanned under computer control in 0.001 nm (125 MHz) spectral steps across the bandwidth of the Bragg reflector while the reflected and transmitted powers are measured on two optical power meters 21. While bandwidth measurements are made, the 3dB fibre coupler 16 and the fibre 11 (with its Bragg grating represented by lines 22) are preferably kept in a temperature controlled housing 23 in order to minimise errors in the results attributable to the effects of temperature upon the Bragg grating.

By way of a first example, the apparatus of Figure 1 was used to create, in a single mode optical fibre with a 20 mole % germania doped silica core, a Bragg reflector whose spectral reflection characteristic is plotted in Figure 3. For this purpose, the laser 12 was an ArF excimer laser with a conventional multimode resonator (no line narrowing) emitting linearly polarised light pulses of approximately 20 ns duration at 193 nm, and the phase grating 10 had a fundamental period of d = 533 nm. The phase grating was

originally designed as a Bragg-Lipman grating, and its order efficiencies, measured for normal incidence, were 14%; 4%; 26%; 20% and 20.5% for the -2, +2, -1, +1 and 0 orders respectively. The lenses 14 provided a spot size measuring approximately 3 mm by 0.3 mm exciting the phase grating 10, with an average fluence of 420 mJ cm^{-2}. For optimum alignment of the fibre 11 in close proximity to the phase grating 10 it was found that the Bragg reflection grating produced in the fibre increased steadily in reflectivity with successive pulses, reaching a maximum value of about 96% after about 10 pulses.

The growth of grating reflectivity over a finite number of pulses is attributed to an incubation effect in which repeated exposure of the doped core leads to a progressive increase in its ultra-violet light absorption coefficient, and consequent fall in the damage threshold. Evidence for this progressive reduction in damage threshold is provided by the results of an experiment performed on a polished fibre preform having the same core composition as that of fibre 11. This preform was irradiated with pulses from the ArF excimer laser and, for a number of different fluences, the number of incubation pulses at that fluence level noted that were required before the onset of ablation. The onset of ablation was monitored using a highly sensitive HeNe laser probe beam deflection system which permits thermal signatures produced by heating of the preform surface to be distinguished from actual ablation (material removal). The results are plotted in Figure 4, which shows that the ablation threshold fluence is dependent upon the number of incubation pulses such that although single pulse ablation requires fluence ≥ 1.7 Jcm^{-2}, ablation will also occur at lower fluence after a finite number of incubation pulses have been delivered. A growth in the amplitude of the thermal signature during this incubation delay gives evidence for this effect arising from a photo-induced increase in the absorption coefficient of the sample.

By way of a second example, the same apparatus of Figure 1 was used to create in a length of similar single mode fibre a Bragg reflector whose spectral reflection and transmission characteristics are respectively plotted in Figures 5 and 6. This second example is distinguished primarily from the first in that, with the phase grating 10 in position, a low reflectivity (typically in the range 1% to 10%) seed grating Bragg reflector is created in the fibre 11, and then, with the phase grating 10 removed, this seed grating is incubated by exposure to one or more further pulses of 193 nm light, thereby enhancing the reflectivity of the Bragg grating, for instance to 96% or greater. In a specific instance a seed grating Bragg reflector with a reflectivity of about 2% was created using a single pulse of about 650mJ cm^{-2} which was then incubated to a reflectivity of about 60% by means of a single further pulse (with the phase grating removed) of about 800 mJ cm^{-2}. In general the use of a single incubation pulse produced the greatest reflectivity, with further pulses causing the reflectivity to decline.

Incubation effects are also observable with Bragg gratings created using the longer wavelength of 248 nm from a KrF excimer laser, but the enhancement is weaker and is generally found more difficult to control. This may be attributable to the fact that the absorption of the germania doped core is less at 248 nm than 193 nm, and hence a greater fluence is needed to initiate damage, this initiation fluence being significantly nearer that producing catastrophic damage to the fibre than is the case when irradiating with 193 nm light.

CLAIMS:

1. A method of creating a Bragg grating in a photosensitive optical waveguide wherein a seed Bragg grating of relatively lower refractive index difference modulation depth is created by exposure of the waveguide to a fringe pattern of illumination using one or more pulses of electromagnetic radiation of sufficient fluence to induce 'damage', as hereinbefore defined, and wherein said modulation depth is enhanced to a relatively higher refractive index difference modulation depth value by exposure of said seed Bragg grating to one or more further pulses of electromagnetic radiation of sufficient fluence to induce further 'damage' in the previously 'damaged' regions of the seed grating.

2. A method as claimed in claim 1, wherein said exposure to said one or more further pulses is an exposure substantially devoid of any fringe pattern.

3. A method as claimed in claim 1 or 2, wherein said exposure of the waveguide to a fringe pattern of illumination is a single pulse exposure.

4. A method as claimed in claim 1, 2 or 3, wherein said exposure of the waveguide to said one or more further pulses is a single pulse exposure.

5. A method as claimed in claim 1, 2, 3 or 4, wherein said exposure of the waveguide to a fringe pattern of illumination, is an exposure to the emission of an ArF excimer laser.

6. A method as claimed in claim 1, 2, 3, 4 or 5, wherein said exposure of the waveguide to said one or more further pulses is an exposure to the emission of an ArF excimer laser.

7. A method of creating a Bragg grating in a photosensitive waveguide, which method is substantially as hereinbefore described with reference to the accompanying drawings.

8. An optical waveguide provided with a Bragg grating by the method claims in any preceding claim.

9. An optical waveguide as claimed in claim 8, which waveguide is an optical fibre.

Amendments to the claims have been filed as follows

1. A method of creating a Bragg grating in a photosensitive optical waveguide wherein a seed Bragg grating of relatively lower refractive index difference modulation depth is created by exposure of the waveguide to a fringe pattern of illumination using one or more pulses of electromagnetic radiation of sufficient fluence to induce 'damage', as hereinbefore defined, and wherein said modulation depth is enhanced to a relatively higher refractive index difference modulation depth value by exposure of said seed Bragg grating to one or more further pulses of electromagnetic radiation of sufficient fluence to induce further 'damage' in the previously 'damaged' regions of the seed grating, wherein said exposure to said one or more further pulses is an exposure substantially devoid of any fringe pattern.

2. A method as claimed in claim 1, wherein said exposure of the waveguide to a fringe pattern of illumination is a single pulse exposure.

3. A method as claimed in claim 1, or 2, wherein said exposure of the waveguide to said one or more further pulses is a single pulse exposure.

4. A method as claimed in claim 1, 2, or 3, wherein said exposure of the waveguide to a fringe pattern of illumination, is an exposure to the emission of an ArF excimer laser.

5. A method as claimed in claim 1, 2, 3, or 4, wherein said exposure of the waveguide to said one or more further pulses is an exposure to the emission of an ArF excimer laser.

6. A method of creating a Bragg grating in a photosensitive waveguide, which method is substantially as hereinbefore described with reference to the accompanying drawings.

7. An optical waveguide provided with a Bragg grating by the method claims in any preceding claim.

8. An optical waveguide as claimed in claim 7, which waveguide is an optical fibre.

9. An optical waveguide as claimed in claim 8, which waveguide is an optical fibre.

Patents Act 1977 Examiner's report to the Comptroller under Section 17 (The Search report) -11-	Application number GB 9410996.4
Relevant Technical Fields (i) UK Cl (Ed.M) G2J (JGF) (ii) Int Cl (Ed.5) G02B	Search Examiner MR C J ROSS Date of completion of Search 15 JULY 1994
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii)	Documents considered relevant following a search in respect of Claims :- 1-9

Categories of documents

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A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages	Relevant to claim(s)
X	Electronics Letters, volumn 30, No 11, 26 May 1994 pages 860-862 "High reflectivity fibre gratings produced by incubated damage using a 193nm Ar Flaser" by P E Dyer et al	1 ar least
X	Optics Letters, Volumn 19, No 6, 15 March 1994 pages 387-389 "Photosensitivity in Ge-doped silica optical waveguides and fibers with 193nm light from an Ar F excimer laser" by J Albert et al	1 at least
X	Application Phys Letters, 62,(10), 8 March 1993 pages 1035-1037 "Bragg gratings fabrication in monomode photosensitive optical fiber by UV exposure through a phase mask" by K O Hill et al	1 at least

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